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LEAN IMPACT ON MANUFACTURING PRODUCTIVITY: A CASE STUDY OF INDUSTRIALIZED BUILDING SYSTEM (IBS) MANUFACTURING FACTORY

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Graphical abstract

Abstract

According to a recent study, Lean Manufacturing (LM) adoption in the Malaysian Industrialized Building System (IBS) industry is still low due to a variety of barriers, including misconceptions, the use of modular coordination, a lack of detailed guidelines and the Lean culture is still in its infancy in the field of IBS. This paper examines the impact of Lean Manufacturing approaches towards the manufacturing productivity in Malaysian IBS Manufacturing factory. An integration method of Value Stream Mapping (VSM) and benchmarking for measuring manufacturing plant performance and total productivity is offered. The company was able to improve its performance in each manufacturing department by implementing a lean approach. After improvement, the overall manufacturing plant performance index increased from 0.75 to 0.78, resulting in a 4.00 percent increase in total factor productivity. The proposed improvement features extracted from essential lean methods such as JIT, TPM and CI can be used by practitioners to increase the level of Lean Manufacturing implementation in Malaysian manufacturing firms.

Keywords: Lean manufacturing, value stream mapping, benchmarking, manufacturing productivity

Abstrak

Menurut kajian baru-baru ini, penggunaan pembuatan kejat (PK) dalam industri sistem bangunan berindustri (SBB) masih rendah disebabkan oleh pelbagai halangan, termasuk salah tanggapan, penggunaan penyelarasan modular, kekurangan garis panduan terperinci dan budaya Lean masih di peringkat awal dalam bidang IBS. Kertas kajian ini meneliti kesan-kesan pembuatan Kejat terhadap produktiviti perusahaan pembuatan di Malaysia. Kaedah integrasi antara Pemetaan Aliran Nilai (VSM) dan Penanda Aras bagi mengukur prestasi dan produktiviti perusahaan pembuatan tersebut. Syarikat-syaikat yang terlibat mampu meningkatkan prestasi dengan melaksanakan pendekatan pembuatan *Lean*. Selepas penambahbaikan, keseluruhan indeks prestasi pembuatan dalam syarikat meningkat dari 0.75 kepada 0.78, yang menunjukkan peningkatan sebanyak 4.00%. Ciri-ciri penambahbaikan yang dicadangkan yang diekstrak daripada kaedah lean penting seperti JIT, TPM dan CI boleh digunakan oleh pengamal untuk meningkatkan tahap pelaksanaan pembuatan kejat dalam firma pembuatan Malaysia.

Kata kunci: Pembuatan Kejat, pemetaan aliran nilai, penanda aras, Produktiviti pembuatan

1.0 INTRODUCTION

Malaysia's construction industry creates a sizable contribution to the country's Gross Domestic Product (GDP) growth, and the Industrialized Building System (IBS) has the potential to sustain the country's GDP in a healthy state [1]. However, statistics show that the construction industry endures to have one of the lowest levels of productivity in the economy. The low level of productivity is a result of a slow adoption of modern technologies and practices. The application of modern technology or productivity tools stems from the lean philosophy and has the potential to increase the productivity and competitive-ness of all IBS practitioners in construction by reducing production costs through economies of scale [2].

According to scholars [3], lean techniques enable construction processes to be managed at the lowest possible cost while maximizing value by taking customer needs into account. As a result, it can provide a sound management strategy for increasing efficiency and productivity in both the construction and manufacturing sectors [4].

The type of organization and its ability to adapt to required change influence the choice of Lean Manufacturing (LM) principle/approach, as well as its implementation and achievement [5, 6, 7, 8]. In the foundry division of the auto part manufacturing industry, [9] stated that manufacturing performance improved by implementing only two lean tools, kaizen and value stream mapping. According to [10], all stakeholders face barriers related to a shortage of skilled labor and new technological applications. Additionally, IBS continues to lack automation and mechanization implementation capabilities due to a lack of investment capacity and resources [11]. Furthermore, the advance technologies such as laser polymer [12], single point diamond turning (SPDT) [13], dry cutting [14] and trochoidal milling [15], which are used in IBS construction industry. Those technologies have been efficiently applied across a wide area, such as 3D printing [16], green prefabrication [17] and carbon footprint [18].

According to a recent study, LM adoption remains low in the IBS industry due to several barriers, including misconceptions [19], the use of modular coordination [20], and a lack of detailed guidelines [19], the Lean culture in the IBS field is still in its infancy [21], despite the fact that its application has demonstrated benefits in streamlining production processes and increasing productivity. To our knowledge, no previous study in the IBS field has concentrated on bridging the gap be-tween LM implementation and productivity enhancement in manufacturing. On the other hand, IBS production delays caused by ineffective logistics management [22], late deliveries and supply [23] and poor cost-benefit analysis [24], will eventually affect the performance, productivity growth, and quality of the products. Hence, a methodology for integrating VSM, benchmarking, and lean manufacturing has been proposed in order to improve manufacturing productivity. The purpose of this study is to determine the impact of LM on manufacturing productivity through the integration of VSM and a benchmarking approach.

The following are the motivations for the integration approach used in this study: (1) The VSM used to identify bottlenecks in manufacturing operations which result in a negative growth rate of manufacturing productivity. (2) By optimizing benchmarking, the firm gained a better understanding of its competitive position, strengths, and weaknesses, and by providing a systematic process for effecting change. As a result, a novel VSM – Benchmarking approach will assist industrialists and practitioners in developing more effective strategies for Lean manufacturing implementation.

The proposed framework of the study will be used as guidelines for other manufacturing sectors similar to the IBS industry. It also contributes by introducing a methodology for benchmarking total productivity in manufacturing plants. Data is collected from various manufacturing departments to begin the detailed case study analysis. In addition, three key indices are used to benchmark manufacturing productivity: variability in productivity, baseline productivity, and the manufacturing plant performance index (MPI).

2.0 METHODOLOGY

The concept of VSM, Benchmarking and essential Lean Methods; Total Productive maintenance (TPM) and Just-in-Time (JIT) integration that is based on the necessity of minimization of the work indispensable to perform a complex analysis on the manufacturing productivity. Figure 1 illustrates the application of the concept to the development of the data collection and analysis Procedure. This case industry is primarily an exporter of IBS components to Southeast Asia. They produce a variety of different models of fabricated aluminium structures. Due to the competitive nature of the market, management is compelled to ensure that the IBS manufacturing plant meets dynamic customer demands and to increase the manufacturing plant's productivity. Thus, the objective was to increase manufacturing plant productivity through the use of a combination of lean tools.

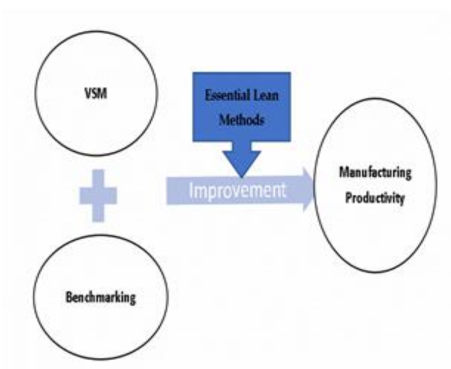

Figure 1 A graphical presentation of Integration between VSM, Benchmarking and Essential Lean Methods on Manufacturing Productivity

2.1 Research Methodology

In the beginning, the manufacturing plant was visited several times and historical data was collected through documentation review regarding start-up approval, shutdowns, maintenance, and; demand and manufacturing plans; and manufacturing plant performance history, including throughput, utilization, and availability. These data information is collected for statistical analysis so that data-driven research decisions can be made The manufacturing plant's current state is mapped using value stream mapping, bottleneck analysis, and productivity measurement. The manufacturing plant's current state value stream map and the results are analyzed to determine future possible improvements.

Additionally, when the enhancements were implemented, a value stream map and productivity analysis were performed to illustrate the manufacturing plant's improved state. Finally, the success of the approach used to increase manufacturing plant productivity through root cause analysis and the application of several lean tools is proved through a comparison of pre- and post-improvement data. The term "root cause analysis" refers to a process or in-depth investigation that identifies the most fundamental factor (or factors) causing a performance variance. This process's primary objective is to ascertain the root cause, or primary cause, of problems that arise during the management of the company's operations.

To accomplish this goal, a brainstorming session will be held. The author, manufacturing managers, and management officers will be collaborated on and discussed the tasks associated with this process, ensuring that all potential root causes of the issue were addressed and analyzed systematically. Brainstorming is the process by which a community generates as many ideas as possible about a particular issue or topic of interest in a short period of time.

Additionally, the approach of brainstorming can assist an organization in fostering innovation and employee engagement [25]. A series of meetings with group members will be held. Any ideas or opinions expressed by group members will be documented by a designated author, who was also the group secretary. Refer to Figure 2 for the flowchart study.

Whereas the following subsections describe an approach for measuring and benchmarking manufacturing plant productivity, as well as a method for estimating performance indices for individual manufacturing departments and a single lean performance index for the entire manufacturing plant.

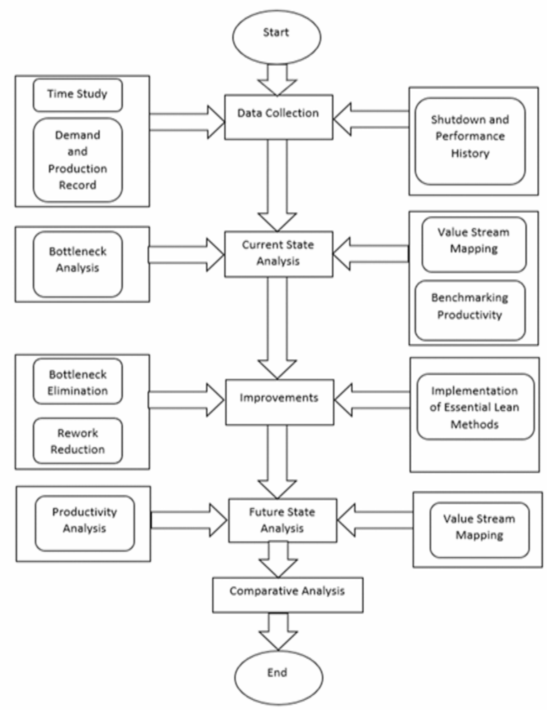

Figure 2 Flowchart study

2.2 Manufacturing Productivity

Manufacturing productivity is determined and influenced by a number of factors, including the actual output per input (labor, machine and overhead), which takes into account the contributions of all manufacturing factors. Three distinct approaches to measuring manufacturing productivity are baseline, actual, and theoretical. The Manufacturing Plant Index (MPI) measures the difference between actual and baseline productivity. Theoretical productivity refers to the maximum output possible under ideal manufacturing conditions, whereas baseline productivity refers to the maximum output possible under normal and standard manufacturing conditions. Manufacturing performance is contingent upon efficient manufacturing operations, and a lack of machine capacity, a labor shortage, a mismatch and in-consistency between planned and actual demand, breakdowns, overtime, and delays, as well as other faulty and substandard items, all contribute to operational inefficiency.

2.2. Theoretical Productivity

Theoretical productivity is calculated using the three productivity factors: labor hours, machine hours, and overhead costs, refer to Equation 1-4 [26, 27].

Equation 1:

[Labor hourly productivity] = $LHP_t^j = \frac{Q_{pp}^j}{(T_{pp}^j \; X \; N_{pl}^j)}$

Equation 2:

[Machine hourly productivity] = $\mathrm{MHP}_t^j = \frac{Q_{pp}^j}{(T_{pp}^j \; X \; N_{pm}^j)}$

Equation 3:

[Overhead cost productivity] = $\mathrm{OHP}_t^j = \frac{Q_{pp}^j}{C_{poc}^j}$

The three single-factors were combined, despite the fact that the units of measurement were different. On a cost basis, this will result in multifactor productivity, refer Equation 4.

[Multifactor productivity] = $\mathrm{MFP}_t^j = \frac{Q_{pp}^j}{\left(C_l^j \; X \; N_{pl}^j + C_m^j \; X \; N_{pm}^j\right) * T_{pp}^j + C_{poc}^j}$

As the equation stated in Equation 1 – 4, Q_{pp}^j is planned manufacturing quantity, T_{pp}^j is planned manufacturing hours, N_{pl}^j is planned number of labours, N_{pm}^j is planned number of machines, C_{poc}^j is planned overhead cost, C_i^j is labour cost per hour and C_m^j is machine cost per hour. MFP_m^j is theoretical multifactor productivity for the manufacturing department.

2.2.2 Actual Productivity

Similarly, actual productivity is calculated using the three productivity factors of la-bour hours, machine hours, and overhead costs, refer to Equation 5-8 [26; 27]

Equation 5:

[Labor hourly productivity] = $LHP_a^j = \frac{Q_{ap}^j}{(T_{ap}^j \; X \; N_{al}^j)}$

Equation 6:

[Machine hourly productivity] = $MHP_a^j = \frac{Q_{ap}^j}{(T_{ap}^j \; X \; N_{am}^j)}$

Equation 7:

[Overhead cost productivity] = $OHP_a^j = \frac{Q_{ap}^j}{C_{aoc}^j}$

The three single-factors were combined, despite the fact that the units of measurement were different. On a cost basis, this will result in multifactor productivity, refer Equation 8.

[Multifactor productivity] _actual = $MFP_a^j = \frac{Q_{ap}^j}{\left(C_l^j \; X \; N_{al}^j + C_m^j \; X \; N_{am}^j\right) * T_{ap}^j + C_{aoc}^j}$

As the equation stated in Equation 5 – 8, Q_{ap}^j is actual manufacturing quantity, T_{ap}^j is actual manufacturing hours, N_{al}^j is actual number of labors, N_{am}^j is actual number of machines, C_{aoc}^j is actual overhead cost, C_i^j is labor cost per hour and C_m^j is machine cost per hour. MFP_a^j is actual multifactor productivity for the manufacturing department.

2.2.3 Baseline Productivity

The term "baseline productivity" is also used to refer to benchmark productivity. This level of productivity is the manufacturing department's short-term objective for overall plant productivity. The baseline is established at 10% of total planned workdays based on the actual highest manufacturing plant productivity [27]. The number set, however, must exceed five workdays. The baseline productivity is calculated by referring to the Equation 9 – 12 [26].

Equation 9:

[Labor hourly productivity] = $LHP_b^j = \frac{\sum_1^n LHP_a^j}{n}$

Equation 10:

[Machine hourly productivity] = $MHP_b^j = \frac{\sum_1^n MHP_a^j}{n}$

Equation 11:

[Overhead cost productivity] = $OHP_b^j = \frac{\sum_1^n OHP_a^j}{n}$

All the factor of baseline productivity in Equation 9 – 11 are combined to compute the baseline multifactor productivity, refer Equation 12.

[Multifactor productivity] _baseline= $MFP_b^j = \frac{\sum_1^n \mathrm{MFP}_a^j}{n}$

Consequently, the three main productivity highlights (theoretical, actual, baseline) are estimated during the Equation 13 – 15 [28,29] for the entire manufacturing plant.

Equation 13:

[Manufacturing plant productivity] _theoretical =

$$MPP_{therotical} = \sum_{j=1}^{m}(W^j \; X \; MFP_t^j)$$

Equation 14:

[Manufacturing plant productivity] _actual =

$$MPP_{actual} = \sum_{j=1}^{m}(W^j \; X \; MFP_a^j)$$

Equation 15:

[Manufacturing plant productivity] _baseline =

$$MPP_{baseline} = \sum_{j=1}^{m}(W^j \; X \; MFP_b^j)$$

W^j is a weight estimated for manufacturing department as the ratio of the department cycle time over the whole manufacturing plant total cycle time. Refer Equation 16 [26]) for weight estimation formula calculation.

Equation 16:

$$W^j = \frac{manufacturing\ department\ cycle\ time}{whole\ manufacturing\ plant\ cycle\ time} = \frac{CT^j}{CT}$$

Referring to Equation 16, CT is computed as follows;

$$\text{Cycle Time} = \sum_{j=1}^{m} \mathrm{CT}^j$$

2.3 Manufacturing Plant Performance Index

Productivity variability is low, indicating that the manufacturing plant is performing well. By contrast, increased variability in productivity indicates that the manufacturing plant is performing poorly [27]. The Manufacturing plant performance index (MPI) is an ad hoc metric. Calculate MPI for the manufacturing department and the entire manufacturing plant using equations 18 and 19 (Rehmani, Usmani,Umer and Alkahtani, 2020; [26]).

Equation 18:

MPI for manufacturing department = $\mathrm{MPI}^j = \frac{MFP_a^j}{MFP_b^j}$

Equation 19:

MPI for whole manufacturing plant = $\mathrm{MPI}^{\mathrm{plant}} = \frac{MPP_{actual}}{MPP_{baseline}}$

3.0 RESULTS AND DISCUSSION

3.1 Data Collection

The formwork manufacturing plant is divided into several subprocesses, beginning with cutting and ending with assembly and packaging. Due to the fact that Company A produces a variety of product designs, this study will concentrate exclusively on SLAB-8. SLAB-8 was chosen for inclusion in the study because it is a critical component of every AL-formwork design and is produced and processed in a manner that is well documented.

The data is gathered through the use of Gemba Walk (observing the work, process and performance of the whole value stream process with a team). Gemba team members communicate and interact with welders, technicians, operators, assemblers, and other critical employees in order to diagnose problems and issues. The dates of overall utilization of each manufacturing subprocess are summarized in Table 1.

Table 1 Data for each manufacturing department plant

Manufacturing department	Cycle time (secs per unit)	Quantity (per hour)	Non-Value-Added Time (secs)	Inventory (Quantity)	Rework (% per month)
Cutting	30	120	2	1500	7
Hole	10	360	5.5	4125	12
Notching	10	360	6	4500	3
Gate	30	120	2.4	4500	26
Welding	60	60	2	1500	41.4

Manufacturing department	Cycle time (secs per unit)	Quantity (per hour)	Non-Value-Added Time (secs)	Inventory (Quantity)	Rework (% per month)
Brushing and Coating	21	171	2.2	1650	15
Final assembly and packaging	15	240	1	750	23

3.2 Current State Analysis

Value Stream Mapping (VSM) was used to map the value added and non-value added activities. Throughout the manufacturing cycle, the total value-added time, which is the sum of the total cycle times for each subprocess, is 176 seconds per unit, while the total non-value-added time, referred to as the total production lead time, is 24.1 days (refer to Figure 4). The notching subprocess is a significant waste of non-value-added time due to a lack of machines. The welding sub-process is the process of joining the main product and its accessories together and is the bottleneck with the lowest hourly manufacturing rate of 60 units (refer to Table 1).

According to Table 1, the welding subprocess accounts for the highest percentage of rework, accounting for 41.4 percent of total manufacturing rework. As a result of the failure/rework documentation, the researchers studied and analyzed the welding sub-process and discovered that the product has a 'black mark' effect due to reaction contamination caused by insufficient gas coverage, graininess, incorrect push angle, and incorrect adjustment and polarity balance.

3.2.1 Productivity Measurement and Benchmarking (Current State)

Perfect manufacturing reflects theoretically achievable productivity under ideal operating conditions. Increased backlogs, delays, discrepancies between planned and actual demand, and breakdowns all contribute to low productivity. Table 2 presents the current Value Stream Mapping, which includes manufacturing quantities, manufacturing hours, labor hours, machine hours, and other costs. Actual and theoretical productivities are estimated (refer to equations 5-8) and theoretical productivities are estimated (refer to equations 1-4) using the data in Table 2 for the current state presented in Table 3.

The baseline productivity (refer to equations 9-12) is based on the best documented actual productivity and a benchmarking of manufacturing productivity that is used to identify, adapt, and implement internal opportunities for achieving the best operations management practices. The baseline for all manufacturing departments is shown in Table 3. For each manufacturing department, the manufacturing performance index (equation 17) is calculated, and the results are shown in Table 3. The cycle time of a unit is the amount of time required to complete a process in its current state (see Figure 4 and Table 2). Calculating the weights for each manufacturing department is based on the total cycle time. The manufacturing plant total productivity model was used to determine the current state of performance of the entire plant (refer to equations 13–19).

$$MPP_{therotical} = \sum_{j=1}^{6}(W^j \text{ x } MFP_t^j) =$$

$$[\, 0.017*1.91 + 0.057*1.91 + 0.057*3.83 + 0.170*1.28 + 0.340*0.48 + 0.119*1.91 + 0.085*2.52] = 1.477$$

$$MPP_{actual} = \sum_{j=1}^{6}(W^j \text{ x } MFP_a^j) =$$

$$[\, 0.017*1.27 + 0.057*1.83 + 0.057*0.94 + 0.170*1.26 + 0.340*0.64 + 0.119*1.85 + 0.085*1.72] = 1.071$$

$$MPP_{baseline} = \sum_{j=1}^{m}(W^j \text{ x } MFP_b^j) =$$

$$[\, 0.017*1.91 + 0.057*1.91 + 0.057*3.83 + 0.170*1.27 + 0.340*0.47 + 0.119*1.92 + 0.085*1.92] = 1.421$$

MPI for whole manufacturing plant = $MPI_{current}$

$$= \frac{MPP_{actual}}{MPP_{baseline}} = \frac{1.071}{1.421} = 0.75$$

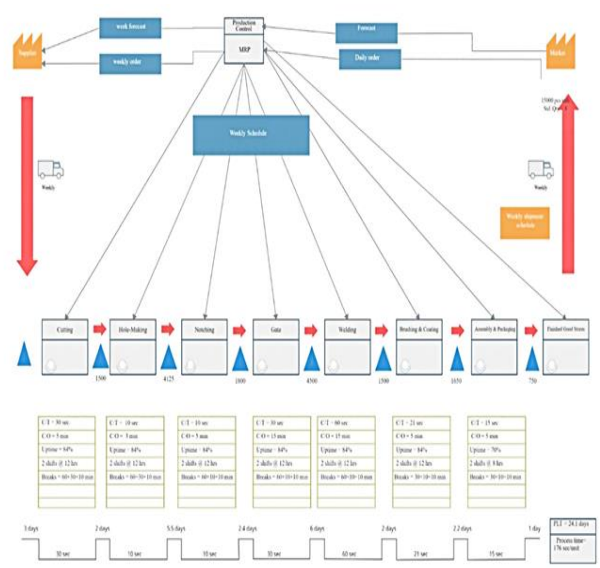

Figure 4 Current state value stream map

Table 2 Current state planned and actual monthly manufacturing quantities, manufacturing hours, number of labors, number of machines and other costs

Manufacturing department	*j*	LHP_{jt}	MHP_{jt}	OHP_{jt}	MFP_{jt}	LHP_{ja}	MHP_{ja}	OHP_{ja}	MFP_{ja}	LHP_{jb}	MHP_{jb}	OHP_{jb}	MFP_{jb}	MPI_{j}
Cutting	1	15,000	575	2	2	7832	14,830	572	3	2	4770	3.52	3.29	30
Hole	2	15,000	575	2	2	7832	14,320	574.33	2	2	4600	3.52	3.29	10
Notching	3	15,000	575	1	1	3916	14,652	570.21	4	2	5250	3.52	3.29	2.4
Gate	4	15,000	575	3	3	11,474	14,553	565.35	3	3	8625	3.52	3.29	6
Welding	5	15,000	575	8	8	18,084	14,568	571.4	6	6	17250	3.52	3.29	900
Brushing and Coating7	6	15,000	575	2	2	7832	14,442	572.33	2	2	4025	3.52	3.29	120
Final assembly and packaging	7	15,000	575	2	1	5940	13,451	573.71	2	1	5500	3.52	3.29	300

Table 3 Theoretical productivities and actual productivities for the current state

Manufacturing department	jpp	jpp	jpl	jpm	jpc	jap	jap	jal	jam	jac	jl	jm	Tj	j
Cutting	5,000	75			832	4,830	72			770	.52	.29	0	.021
Hole	5,000	75			832	4,320	74.33			600	.52	.29	0	.007
Notching	5,000	75			916	4,652	70.21			250	.52	.29	.4	.002
Gate	5,000	75			1,474	4,553	65.35			625	.52	.29		.004
Welding	5,000	75			8,084	4,568	71.4			7250	.52	.29	00	.65
Brushing and Coating 7	5,000	75			832	4,442	72.33			025	.52	.29	20	.09
Final assembly and packaging	5,000	75			940	3,451	73.71			500	.52	.29	00	.22

The essential lean methods such as Total Productive Maintenance, Just In Time and Continuous Improvement are being implemented to maximize performance value through pre-assessment of the manufacturing plan. When the baseline and actual productivity values are equal, maximum productivity is achieved. The following sections demonstrate several measures taken to increase productivity through the use of essential lean methods, as well as the proposed improvements to activities and the impact of MPI.

Post-current state analysis, various problems and issues are recognized in the manufacturing plant, such as rework percentage, bottlenecks, and lead time for the whole stream. Within production capacity, these issues directly and indirectly influence the productivity of a manufacturing plant, and the MPI measured for the current state is 0.75. Several lean tools such as Total Productive Maintenance, Just In Time and Continuous Improvement were identified and used to improve manufacturing productivity and resolve issues. The results of the current value stream map indicate that the welding department has the maximum percentage of rework and non-value-added time per unit. It is a department that is being worked on.

3.3 Essential Lean Methods Implementation for Productivity Enhancement

3.3.1 Root Cause Analysis

The welding department is responsible for 41.4 percent of reworks, according to current state research findings (refer to Table 1). This particular department was the subject of the root cause analysis because it was the source of the manufacturing process's bottleneck. Pre-welding (before), peri welding (during), and post-welding findings were all classified (after). The issues' underlying causes were also discussed, as were their detrimental effects on the organization.

Table 4 summarizes the brainstorming activities, which were classified into the following categories: process, problem, and impact

Process	Definition	Problem	Possible Cause	Effect	Impact
Pre-weld	Preliminary welding activity for coordinator or welders starts their welding	High rework	Inappropriate welding pre-treatment (Cleaning)	Smut, grime, and other impurities cause the ineffectiveness of the weld.	Poor product quality
			A tool sets and fixtures not kept properly.	Wasting time when operator rummages tools	High operation cost
			Aluminum sheets are placed in exposed area and unproper stacked	Improper penetration into the metal/aluminum	Insufficient manufacturing space
Peri-weld	The activity of welders or operators through-out the welding process		Improper gun angle, incorrect range of nozzle-to-workspace distance and incorrect apply the right parameters.	Weld spatter and defects.	Poor product quality
			Inconsistencies in shielding gas	Affect the quality of weld whereby the hydrogen and oxygen contaminated within the weld.	Lack of knowledge Poor product quality
			Lack/Shortage of gas during the welding process.		High operation cost
			Reading the right welding symbol		High cost of service
Post-weld	The activity after the welding process		Using air duster compressor to cool down the weld aluminum.	The welded joint will be cracked due to internal stress exceeded the strength of the weld.	Poor product quality

Pre-welding is a preparatory activity for coordinators and inexperienced welders. The problem begins during the pre-welding phase with inadequate welding pre-treatment; welders do not thoroughly clean the metal prior to beginning the welding process. Smut, grime, and other impurities impede the effectiveness of the weld (refer Figure 5).

Figure 5 Smut and impurities observed in pre-welding phase

Apart from that, the metal/aluminum should be free of any coatings that might obstruct proper penetration, as well as free of oxide; however, some aluminum sheets are exposed and improperly stacked. Peri-welding is a term that refers to the work that welders or operators perform during the welding process. Operators frequently run into technical difficulties during this phase, including an incorrect gun angle, an incorrect nozzle-to-workspace distance range, and an incorrect application of the proper parameters. Apart from that, inconsistencies in shielding gas composition are a significant cause of spatter and weld defects. By contaminating the weld with hydrogen and oxygen during the welding process, a lack of gas degrades the weld's quality. Additionally, operators have a proclivity for misreading the correct welding symbol. This is due to a lack of an effective documentation system and the absence of a leader who controls and monitors the production of each drawing for a particular product. The term "post welding" refers to the activities that take place after the welding process is complete. PWHT, or Post Weld Heat Treatment, is a routine process that is performed following welding to eliminate residual stress in aluminum, which results in the loss of some mechanical and microstructure properties. Operators who cool welded aluminum with air duster compressors do so ineffectively, resulting in high rework rates. During the solidification phase, the welded joint will crack due to internal stress exceeding the weld's strength (refer to Figure 6).

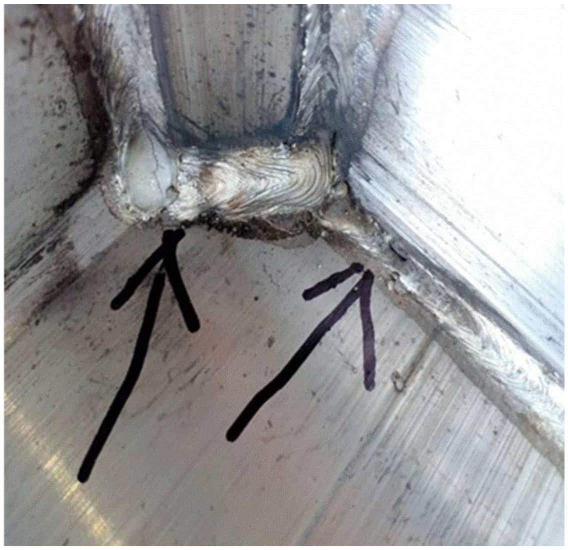

Figure 6 Cracked welded joint observed due to high internal stress

Apart from increasing the rework rate, the high volume of backlogs has an effect on the warehouse's space utilization. Additionally, the rework process takes time, and the company pays overtime to welders to complete the rework, which increases overhead costs and reduces the company's productivity rate. Following several brainstorming sessions, alternatives were suggested for resolving pre-welding issues using a lean approach.

By developing and implementing those strategies, the company responded to the problems outlined in the preceding section. These strategies were implemented using Lean methods such as JIT, TPM, and CI, which increased operational efficiency and thus the company's sustainability. Table 5 summarizes the strategy, the suggested enhancements through the implementation of essential Lean methods, and the anticipated impact on the company's long-term performance.

3.3.2 Improvement Through Lean Manufacturing Implementation

Table 5 shows the improvement through lean manufacturing implementation.

Root Cause	Lean Methods	Improvement	Impact on Performance
Lack of inspection routine	TPM	Scheduled inspection activity	Improve effectiveness of the machine by reducing breakdown through Preventive Maintenance
Lack of chain of command		Appoint a leader or person in charge in handling the pre-welding activities	Allows communication between operator and maintenance department smooth and prevent a major downtime occurs
Lack of safety awareness		Register and participate the workers on government initiatives in production safety	Prevent any damage on electrical accidents
Poor post heat treatment		New SOP on Pre-Welding Heat Treatment (PWHT) on aluminum should be introduced	Reduce the internal stress and crack of welded joint
Lack of cleanliness and poor discipline	CI	The proactive effort of 5S	Sustainment of 5S awareness produces a self-discipline welder
			Workspace clean and organized
		Tool shelf was recommended to place tool sets and fixtures and kept properly	Effective time during product changeover
Massive numbers of backlog due to last minute change in order	JIT	Effective JIT production scheduling	Lowering the number of stocks holding in storage space and allows the pre-treatment aluminum stock keep in organize and space sufficient
Poor delivery due to larger Work in Process (WIP)		Using Inventory Management System (IMS) software	Increases supply chain visibility and strategic sourcing

Authors suggested a scheduled inspection activity from a TPM standpoint. According to [30; 31; 32], inspection is a critical component of Autonomous Maintenance (TPM Eight Pillars), with the goal of increasing the machine's effectiveness by minimising breakdown. Its purpose is to educate welders about the normal wear and tear that occurs with the tools they use. Additionally, the operator could keep an eye on the hour metre and notify the maintenance department when the next welder requires preventive maintenance (PM). Due to the absence of a chain of command, major downtime is always inevitable when broken tools or machines are simply repaired by an inexperienced or ill-informed operator. As a result, the researchers recommend that the company appoint a leader or person in charge of pre-welding activities, facilitating communication between the operator and the maintenance department and avoiding significant downtime. [33] asserts that establishing a leadership team and a structured education program for TPM leaders will improve TPM deployment throughout the manufacturing process. According to [34], knowledge and specialized training is one of the crucial drivers in manufacturing practice specifically in SMEs. In order to derived the concerning issues on productivity, element of safety will be a great importance (35; 36). Therefore, the authors suggest that company encourage their employees to take part in government-led initiatives such as safety seminar and training to enhance their awareness on safety approach in manufacturing environment. Maintenance personnel, for example, who attend the safety workshop, can perform safety-related activities such as cleaning and inspecting the power distribution system to avoid any damage caused by electrical accidents.

According to by [37] the unproper heat treatment will affect the aluminium mechanical properties. High quenching rate has less homogeneous cooling rate and produces a distorted and cracked product which usually occur from uneven cooling. A new standard operating procedure (SOP) for pre-welding heat treatment (PWHT) on aluminium should be implemented as suggested by [37] and wire arc additive solution as suggested by [38] which increase the durability and strength of aluminium, thereby reducing internal stress and cracks in the welded joint.

From a Continuous Improvement (CI) perspective, proper documentation and recording of 5S (sort, set in order, shine, standardise, and sustain) activities is required to improve the company's and, more specifically, the welding department's cleanliness and hygiene culture. Proactive measures such as routine tasks, mopping, and brushing away impurities will help keep the workspace clean and organised. Maintaining a 5S mindset results in a self-disciplined welder. The company should arrange for appropriate training in welding technique and exposure to the consequences of welding misconduct. It ensures that operators and welders have the necessary knowledge and skills, and it can improve the equipment's quality and performance rate, thereby increasing productivity [39; 30, 31; 32]. Apart from that, a tool shelf was recommended for storing tool sets and fixtures. During product changeover, the operator or welder will have effective time.

Aluminium without pre-treatment occurs as a result of a massive backlog from a Just-in-Time (JIT) perspective, and it can only be avoided through effective JIT production scheduling [40].

Due to the company's custom-based products, it frequently faces last-minute order changes. The research suggests implementing a 'pull system' driven by customer demand for JIT production in order to reduce the number of stocks held in storage space and to organise and space sufficient pre-treatment aluminium stock, thereby lowering the rework rate. Due to the absence of a document management support system in the demand and supply forecasting process, the researchers recommend that the company invest in analytical technology through the use of Inventory Management System (IMS) software. By increasing supply chain visibility and strategic sourcing, this effort benefits the JIT pull system [41; 42]; Nugroho, Christiananta, Wulani and Pratam, 2020). Disruptions, such as shortages of raw materials and late deliveries, contributed to the backlog. Aluminium sheets are placed in exposed areas due to increased Work-in-Process (WIP) and insufficient space. The company must enhance the flow of information between supplier and customer by increasing the visibility of the supply chain through the use of the electronic data interchange. According to [42] the entire system should be interconnected through the use of information technology systems. All processes must be automated, which results in the loss of less efficient resources.

Productivity Evaluation (Future State Analysis)

~~A~~ Future State VSM is depicted (refer to Figure 7). The total cycle time, or value-added time, is 156 seconds per unit, while the non-value-added time, or production lead time (PLT), is 22.6 days. Monthly manufacturing quantities, manufacturing hours, labour hours, machine hours, and other costs are presented in Table 2. The future state map, where actual productivities are calculated (refer to Eqs. 5–8, and presented in Table 3. Theoretical and baseline productivity remain constant with those calculated previously (see Table 3). After improvements (refer to Figure 7), the cycle time required to process a unit is altered and used to calculate the weights for each manufacturing department (refer to Table 3). After improvements, the whole plant performance index is calculated as follows (refer to Eqs. 13–19).

$$MPP_{therotical} = \sum_{j=1}^{6}(W^{j} \text{ x } MFP_{t}^{j}) =$$

[0.019*1.91 + 0.064*1.91 + 0.064*3.83 + 0.192*1.28 + 0.256*0.48 + 0.134*1.91 + 0.096*2.52] = 1.605

$$MPP_{actual} = \sum_{j=1}^{6}(W^{j} \text{ x } MFP_{a}^{j}) =$$

[0.019*1.27 + 0.064*1.83 + 0.064*0.94 + 0.192*1.26 + 0.256*0.46 + 0.134*1.85 + 0.096*1.72] = 1.197

$$MPP_{baseline} = \sum_{j=1}^{m}(W^{j} \times MFP_{b}^{j}) =$$

[0.019*1.91 + 0.064*1.91 + 0.064*3.83 + 0.192*1.27 + 0.256*0.47 + 0.134*1.92 + 0.096*1.92] = 1.543

MPI for whole manufacturing plant =

$$MPI_{current} = \frac{MPP_{actual}}{MPP_{baseline}} = \frac{1.197}{1.543} = 0.78$$

The objective was to maximise the performance of the manufacturing plant through a comprehensive, lean philosophy. According to VSM's current state, the PLT and process time for the entire manufacturing plant are approximately 24.1 days and 176 seconds per unit. Whereas, the PLT and process time for the entire manufacturing plant are approximately 22.6 days and 156 seconds per unit with the future state VSM (after improvements). Additionally, by combining essential lean methods such as kaizen (continuous improvement), JIT and TPM, additional benefits are realised through a decrease in rework and failure due to welding section issues. The manufacturing plant's current state productivity assessment reveals that the welding manufacturing department's actual multifactor productivity is extremely low at 0.64 compared to other manufacturing departments, whereas the assembly department's actual multifactor productivity is a maximum of 2.53. Addition-ally, the current state of total actual productivity for the entire manufacturing plant is 1.071, which is below both the theoretically maximum achievable total productivity and the baseline productivity level of 1.477 and 1.421, respectively. The current state MPI of the entire manufacturing plant is found to be positive and equal to 0.75, while the desired MPI is 0.78. This distinction directs industry management and decision makers toward de-sired improvement activities for manufacturing plants in their current state. Under typical manufacturing plant operating conditions, management strives for maximum productivity. As a result, a lean approach was taken to increase the factory's productivity in Malaysia. After improvement, the total actual multifactor productivity (MPP) of the entire manufacturing plant increases to 1.197, exceeding the current state actual MPP but falling short of both the estimated maximum theoretically achievable MPP and the estimated baseline MPP. When the entire manufacturing plant performance index (MPI) of the cur-rent state is compared to the MPI of the improved state, it is discovered that the improved state's MPI is positive 0.78, which is greater than the estimated desired benchmarked MPI of 0.76. Actual productivity growth from the current state to the improved state of the IBS manufacturing plant is now 4.00 percent, which is a commendable accomplishment. This study has made a number of significant contributions to a term of yield and employee's morale and it provides evidence to managers that the integration between the productivity benchmarking with VSM approach can be a crucial lever to strategically align lean manufacturing. These point out the advantages and practicability of the allocation's increment for improvement within the operation, which can be achieved after yield is boosted due to productivity growth, but also the company will have the advantages on the social impact through employee's participation and innovative work behaviour.

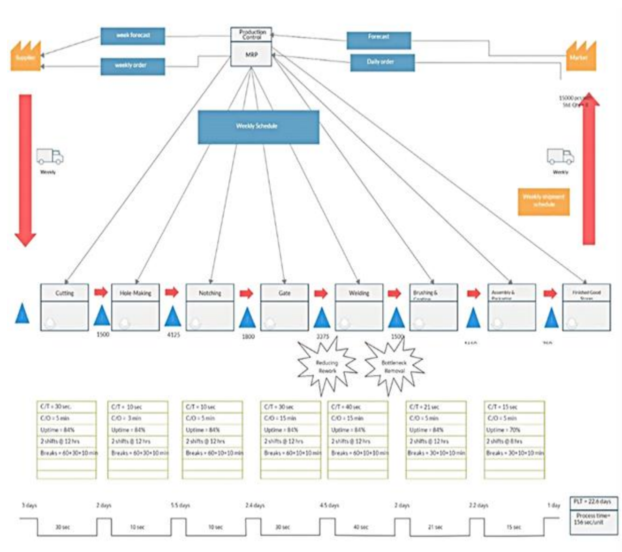

Figure 7 Future state value stream map

4.0 CONCLUSION

To conclude, the LM strategy improves manufacturing productivity in Malaysian IBS factories. The objective was to maximize the MPI's value through the simplest and most efficient implementation possible. The welding department, according to the current value stream mapping, is the bottleneck station due to its high PLT value. Numerous strategies for circumventing the bottleneck have been implemented. Following that, lean manufacturing techniques such as Just-in-Time (JIT), Total Productive Maintenance (TPM), and Continuous Improvement (CI/KAIZEN) were implemented to eliminate bottlenecks associated with welding operation problems and issues. The company was able to reduce the cycle time of the welding substation by 33%, from 60 to 40 seconds per unit. PLT has decreased by nearly 6.3 percent, from 24.1 to 22.6 days, according to the revised value stream map. Additionally, the implementation of critical LM methods increased the overall MPI by 4.00 percent, from 0.75 to 0.78, indicating that the company's entire manufacturing operation is increasing in value. Correlations between performance measures may be added as a future scope, depending on the extent to which leanness is successfully implemented. This is a novel approach in Malaysia's manufacturing industry. To this end, the present case study's transferrable knowledge can be summarized as follows: (1) A proposed integration method for resolving bottlenecks can be used as a benchmark for productivity monitoring and evaluating by manufacturers and practitioners in non-manufacturing fields. (2) Proposed Lean Methods contribute to the manufacturing area of IBS manufacturers, which may be beneficial for other industrial applications. (3) The improvement features proposed here can be used by practitioners to increase the level of Lean Manufacturing implementation in Malaysian manufacturing firms. As a result, considerable implementation space exists. As a result, it can be concluded that lean manufacturing is a viable method of operation management. Nonetheless, additional attention and effort, as well as training and operational teams, are required to ensure the success of lean implementation in Malaysia.

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